SCIENCE

FRIDAY, MAY 31, 1912

CONTENTS

MSS. intended for publication and books, etc., intended for review should be sent to the Editor of SCIENCE, Garrison-on-Hudson, N. Y.

THE BUILDING OF "CORAL" REEFS

A coral reef is a ridge or mound of limestone, the upper surface of which lies or lay at the time of its formation, near the level of the sea, and is predominantly composed of calcium carbonate secreted by organisms, of which the most important are corals.

THE above is the opening sentence of an able and suggestive paper by Dr. Thomas Wayland Vaughan on "Physical Conditions under which Paleozoic Coral Reefs were formed," published last year in the *Bulletin of the Geological Society of America.*[1] If we pass over for the moment the question as to just what is meant by "near the level of the sea," a point that is discussed by Dr. Vaughan later on, the part of the above definition that particularly challenges attention is the final clause, "of which the most important are corals." It is not to be denied that this last statement embodies the long-standing and still prevalent view as to the origin and composition of coral reefs and, in fact, it might seem at first sight to be quite axiomatic that corals should be the most important constructive agents in the formation of "coral" reefs. But in view of the fact that some rather recent studies indicate that lime-secreting plants have been much more important than the corals in the formation of certain "true coral reefs" and in view of the few borings and analytical studies of so-called "coral" reefs thus far made, there would seem to be sufficient ground for contending that the whole question as to the relative general importance of lime-secreting animals and lime-secreting plants in the formation of reefs is still an open one. From

[1] Vol. 22, p. 238.

what may be observed to-day in the tropics as to the relative abundance of calcareous marine plants and calcareous marine animals and from what has been determined by the study of the cores obtained by boring into coral reefs, it would appear that sometimes the plants predominate and sometimes the animals. As Dr. Vaughan points out, there are good grounds for believing that the conditions attending the formation of coral reefs in ancient times were not very different from those that prevail at present. In any event, the definition quoted above is intended to be a general one and its validity is to be tested by application to recent and modern conditions as well as to those of long-past geological ages.

The best-known example of a thorough and detailed study of the nature of a coral reef is embodied in a quarto work of more than four hundred pages published by the Royal Society of London in 1904 and entitled "The Atoll of Funafuti: Borings into a Coral Reef and its Results: Being the Report of the Coral Reef Committee of the Royal Society." Funafuti was selected for this study because it was considered a "typical" coral reef or island. Several borings were made by members of the three successive expeditions that visited the atoll, the first attempts being only partially successful, and the cores thus obtained were brought back to England for careful study. The main boring was finally driven down to a depth of 1,114½ feet. *Lithothamnion*, a hard stone-like red coralline seaweed, of the group commonly known to zoologists and geologists as "nullipores," was found to be more or less abundant through the entire length of the boring; *Halimeda*, a calcified green seaweed, was locally very abundant from 28 to 1,096 feet in depth. Professor J. W. Judd sums up the general results of the analysis of the cores as follows:

> Dr. Hinde's carefully drawn up lists show that from top to bottom the same organisms occur, sometimes plants, sometimes foraminifera, and sometimes corals predominating (p. 174).

It is to be observed that he mentions plants first. Moreover, Mr. A. E. Finckh, who was one of the members of the expedition and wrote the chapter on "Biology of Reef-forming Organisms at Funafuti Atoll," definitely groups these organisms in order of their reef-building importance as follows: "(1) *Lithothamnion;* (2) *Halimeda;* (3) the Foraminifera; (4) the Corals." It will be noted that the first two places in this ranking are given to members of the plant kingdom and that the corals, the "most important" reef-building organisms of Vaughan's definition and of the still prevalent popular belief, are relegated to a fourth position. This naturally raises the somewhat academic, though chiefly biologic, question, "When is a 'true coral reef' not a coral reef?" It raises also a serious question as to whether the continued use of "coral" reef for structures that have been built up largely through the agency of plants is not responsible for false ideas and widespread mental confusion.

That the opinion of Mr. Finckh in regard to Funafuti is not his alone, is evident from the following statement by J. Stanley Gardiner, who, being a professor of zoology in Cambridge University, should be free from any suspicion of bias in favor of the plants:

> The reef [of Funafuti] seems to have been mainly formed by the growth of nullipores, which are now building up masses outside the rim and adding them on the reef, causing its extension seawards.[2]

[2] "The Coral Reefs of Funafuti, Rotuma and Fiji, together with some Notes on the Structure

Incidentally, for the benefit of botanists, who have long abandoned the term "nullipore," even though the enforcement of priority principles in nomenclature may possibly lead to its revival, it may be explained that the generic name *Nullipora*, as proposed by Lamarck in 1801, was made to include four species of calcareous organisms believed by him to be animals, but all of which, probably, were plants and members of the family Corallinaceæ of the red algæ—the family popularly known as the "coralline seaweeds." Furthermore, they were of the subgroup sometimes spoken of as the "unsegmented" corallines, including the numerous forms that until recently have passed under the widely inclusive generic name *Lithothamnion*, but now commonly segregated into smaller generic groups known as *Lithothamnion*. *Lithophyllum*, *Goniolithon*, *Phymatolithon*, etc. But the term "nullipore," which has remained the almost exclusive possession of the zoologists and geologists, while applied chiefly and properly to the stone-like or coral-like red algæ, has occasionally been made to cover also undoubted animals and was used by Alexander Agassiz[3] to include also some of the very different calcified green algæ. Alexander Agassiz, by the way, was one of the first to emphasize the importance of "nullipores" in reef-building, but the loose way in which he frequently referred to "nullipores and algæ," "corallines and algæ" may easily have hidden from many of his non-botanical readers the fact that his "nullipores" and "corallines" were just as truly algæ as are any of the species of *Fucus*.

But, to return to our main subject, there is considerable evidence that the dominance of plants in building up the "true coral island" Funafuti is not an exceptional or isolated instance of their activity in this direction. Professor Gardiner, in describing the reefs of Fiji, in the paper referred to above, says:

> The parts of "compact homogeneous texture" are very numerous and are formed, I believe, mainly by carbonate of lime secreted by incrusting nullipores. The importance of the incrusting nullipores, in the formation of the reefs of the Central Pacific can not be overestimated.[4]

Again,[5] in discussing the foundation of atolls in general, Professor Gardiner remarks that

> The chief building organism is *Lithothamnion*, the bathymetrical zone of which must be limited to a large degree by the extent to which light can penetrate seawater.

In another case,

> This nullipore [*Lithophyllum craspedium*], Finckh says, is actually the reef-former at Onoatoa [Gilbert Islands]. He saw no live coral there, but everywhere on the lagoon and ocean-face immense masses of this particular nullipore.[6]

That lime-secreting plants rather than corals are sometimes, at least, the dominant reef-formers in the Indian Ocean as well as the Pacific, is shown by the following remark by Professor Gardiner:

> The reefs of the Chagos are in no way peculiar, save in their extraordinary paucity of animal life. . . . However, this barrenness is amply compensated for by the enormous quantity of nullipores (*Lithothamnia*, etc.) incrusting, massive, mammillated, columnar and branching. The outgrowing seaward edges of the reefs are practically formed by their growths and it is not too much to say that, were it not for the abundance and large masses of these organisms, there would be no atolls with surface reefs in the Chagos.[7]

and Formation of Coral Reefs in General," *Proc. Camb. Philos. Soc.*, Vol. 9, pp. 417–503, 1898.

[3] *Bull. Mus. Comp. Zool. Harv. Coll.*, Vol. 14, p. 82, 1888.

[4] *Loc. cit.*, p. 477.

[5] *Loc. cit.*, p. 501.

[6] "Fauna and Geography of the Maldive and Laccadive Archipelagoes," Vol. I., p. 462.

[7] *Trans. Linn. Soc. London*, Zool., 2d ser., Vol. 12, pp. 177, 178, 1907. Also, *Nature*, Vol. 72, pp. 571, 572, where a photograph of this *Lithothamnion* reef is published.

That the coralline algæ form extensive banks and reefs in the Dutch East Indies also is indicated by the following quotation from Mme. A. Weber-van Bosse's report on "The Corallinaceæ of the Siboga Expedition":[8]

> Near the coast of Haingsisi, an island near the S. W. point of Timor, the Siboga anchored twice . . .; the second time good luck favoured us, it was springtide, the water sank very low and we could observe that the whole reef . . . consisted chiefly of *Lithothamnion erubescens* f. *Haingsisiana*. It was remarkable that the branching knolls remained quite dry during several hours of the day, exposed to the glare of the tropical sun, and that this seemed not to injure them. . . . This *Lithothamnion*-bank struck me, because it is such a unique sight to see the ground, as far as the eye can reach, covered by the pretty beautifully pink-coloured knolls, which are heaped up so close together that, while walking, one crushes them continually, making a peculiar noise as of broken china. We encountered, however, other and perhaps more instructive *Lithothamnion* banks during our voyage.

Bermuda, as is generally known, was commonly considered a "true coral" island until the studies of Alexander Agassiz[9] and of Henry B. Bigelow[10] indicated that the corals have played a rather minor part in its upbuilding. Dr. Bigelow believes (*loc. cit.*, p. 582) that "algæ probably form the greatest mass" of what he terms the "shell sands" of Bermuda, and it is of interest to note that Sir John Murray in reporting the results of the *Challenger* Expedition intimates that the calcareous seaweeds and their broken down fragments were the dominating elements in three out of four analyzed samples of so-called "coral" sand or mud from Bermuda. Dr. Bigelow, in connection with his critical studies of "The Shoal-water Deposits of the Bermuda Banks," made a series of dredgings on the Challenger Bank, nine miles or more from Bermuda. His dredge brought up chiefly "calcareous pebbles," which on examination proved to be formed by a species of *Lithothamnion*. These were growing at a depth of from 30–50 fathoms, a depth too great for most of the corals. In summing up the results of these studies, Dr. Bigelow writes:[11]

> The dredgings from the Challenger Bank add to the evidence already accumulated to prove the great importance of the nullipores as reef builders. . . . This process taking place over the Challenger Bank, where there is no direct evidence of either elevation or subsidence, has raised it to within some thirty to fifty fathoms of the surface of the sea, a depth where a few corals already flourish. If we imagine this process as continuing until the bank rises to within about twenty fathoms of the surface, we should then have excellent conditions for the formation of a coral reef. Of course in such upbuilding the nullipores constitute only a part, though a most important one, of the whole growth.

It would appear from this observation of Dr. Bigelow's and from various other records that the lime-secreting seaweeds flourish and are effective reef-builders in greater depths than is the case with the corals. Dr. Vaughan, in the paper under discussion, quotes Professor J. Stanley Gardiner as authority for the statement that the "nullipores extend to a depth of 35 fathoms" in the Maldives, but Mr. A. E. Finckh in his dredging operations about Funafuti frequently found them in "depths of over 100 fathoms *in situ*"[12] and also found *Halimeda* alive down to 45 fathoms. From Alexander Agassiz's description of the Pourtalès Plateau off the southern coast of Florida, one seems justified in inferring that he found incrusting

[8] "Siboga-Expeditie," Monographe LXI., p. 4, 1904. Interesting photographs of the *Lithothamnion* bank are here published.

[9] *Bull. Mus. Comp. Zool. Harvard Coll.*, Vol. 26, pp. 205–281, 1895.

[10] *Proc. Am. Acad. Arts and Sci.*, Vol. 40, pp. 557–592, 744, 1905.

[11] *Loc. cit.*, pp. 589, 590.

[12] "The Atoll of Funafuti," p. 134.

"nullipores" in a living condition at depths of from 250 to 350 fathoms.[13] According to Dr. Vaughan, it is generally conceded "that 25 fathoms is the greatest depth" at which the reef-building corals work effectively, "although an occasional reef species may extend downward to a depth of 40 fathoms."

Besides flourishing in greater depths than the corals, the lime-secreting seaweeds are much less dependent upon high temperatures than are the corals. Sir John Murray has remarked[14] that "in the polar seas and in the cold water of the deep seas there is, as is well known, a feeble development of all carbonate of lime structures in marine organisms," a statement that may be true enough in a comparative way for organic nature as a whole, but is manifestly much more true of the corals than of the coral-like red algæ. The coralline algæ are, locally at least, abundant from 73½° south latitude[15] to 79° 56′ north latitude.[16] The late Professor Kjellman, of Upsala, has stated[17] that off the coasts of Spitzbergen and Nova Zembla *Lithothamnion glaciale* "covers the bottom in deep layers for several miles" mostly in 10 to 20 fathoms of water, and he adds that "in the formation of future strata of the earth's crust in these regions it must become of essential importance." Another species of *Lithothamnion* is said to form banks on the coasts of Iceland and of Greenland. Foslie[18] states also that

North of the polar circle on the coast of Norway banks have been met with which cover the bottom for several miles and plants appear in immense masses, frequently representing only one species.

A good account of "Algæ as Rock-building Organisms," with special reference to their occurrence in ancient limestones, was contributed to *Science Progress*[19] in 1894 by Professor A. C. Seward, of Cambridge University. An interesting feature of Professor Seward's paper is his summary of the results of J. Walther's studies of a *Lithothamnion* bank in the Bay of Naples about 30 m. below the surface of the water:

By action of the percolating water the *Lithothamnion* structure is gradually obliterated, and the calcareous mass becomes a structureless limestone. Walther applies his knowledge of this recent algal deposit to the examination of a Tertiary "Nulliporenkalk" near Syracuse. In many parts of this formation there occur well-preserved specimens of *Lithothamnion*, but in others a gradual obliteration is observed of all plant structures until the rock becomes entirely structureless. A similar instance of structureless limestone is described from the Lias of Todten Gebirges [Todtes Gebirge].

In Bermuda, southern Florida and the West Indies one finds among the living reef-building organisms and in their distribution and association many of the general types described by Gardiner and others for the Pacific and Indian oceans, even though "true atolls" of the Pacific type may be rare or quite wanting. There are banks and reefs that appear to consist almost wholly of calcareous plants others that are almost "pure stands" of corals, and yet others where these two elements are intermingled. In the last case, the "nullipores" often seem to be overgrowing and smothering the corals, as has been observed in the Pacific and elsewhere. In view of all of the evidence now available it would be a bold man who would venture to say

[13] *Bull. Mus. Comp. Zool. Harvard Coll.*, Vol. 14, p. 287, 1888.

[14] *Natural Science*, Vol. 11, p. 26, 1897.

[15] Foslie, M., "Corallinaceæ, in National Antarctic Expedition, Natural History," Vol. 3, 1907.

[16] Kjellman, F. R., "The Algæ of the Arctic Sea," *Kongl. Sv. Vet.-Akad. Handl.*, Vol. 20, No. 5, p. 96, 1883.

[17] Kjellman, *loc. cit.*

[18] In Gardiner, "The Fauna and Geography of the Maldive and Laccadive Archipelagoes," Vol. 1, p. 462.

[19] Vol. 2, pp. 10–26.

that the corals are secreting and depositing any more calcium carbonate in the West Indian region than are the calcareous algæ. The massive beds of *Halimeda opuntia* off the Florida Keys (the same species, by the way, that is filling the lagoons of some of the South Sea atolls) are striking, as are the banks of *Goniolithon strictum* in the Bahamas and reefs of *Lithophyllum Antillarum* and *Lithophyllum daedaleum* along the shores of Porto Rico, yet probably none of these are so conspicuous and massive as are certain local aggregations of living corals in the same general regions. However, the lime-secreting plants appear to be much more generally and widely distributed, both horizontally and vertically, than are the corals, and the rate of growth is, of course, a factor of importance in any attempt to estimate the relative lime-depositing activity of corals and calcareous algæ. The notable studies and measurements of living corals by Dr. Vaughan at the Tortugas station of the Department of Marine Biology of the Carnegie Institution of Washington are beginning to throw a most welcome light on the rate of growth of the corals. No similar records of the rate of growth of the calcareous red algæ have as yet been published, so far as we are aware, but from the fact that these plants often cover and smother living corals one is perhaps justified in assuming that the growth of certain kinds of coralline algæ is superficially, at least, more rapid than that of certain kinds of corals. For the rate of growth of the calcareous green algæ we have scarcely any definite records except one by Finckh,[20] who observed in Funafuti a radio-vertical growth of three inches in six weeks in a tangle of *Halimeda opuntia* that had found its way through a hole in a board. This growth-rate, which is possibly more than a fair general average for the species, seems much more rapid than any thus far attributed to the corals.

[20] "The Atoll of Funafuti," p. 146.

With the dominance in reef-building activities resting sometimes with the calcareous algæ and sometimes with the corals, and with the Foraminifera and other groups also playing their parts, the problem of determining the "most important" constructive element in the calcium carbonate reefs of the world, ancient and modern, is naturally a most complicated and difficult one and one that may never be solved to the full satisfaction of those most interested. Alexander Agassiz, in 1894, in summing up the general result of his explorations of Bermuda and the Bahamas, which had revealed a condition of things not realized before, frankly remarked that it was a "significant example of how little we as yet know of the history of the formation of the coral reefs."[21] As a general proposition this remark seems almost as apt now as when it was made in 1894. However, since the day of the first illuminating borings into the "true coral atoll" of Funafuti, much evidence has accumulated tending to show that the importance of the corals in reef-building has been much over-estimated and that the final honors in this connection may yet go to the more humble lime-secreting plants.

Marshall A. Howe
New York Botanical Garden

UNIVERSITY CONTROL

II

In a review of the different factors concerned with the administration of a university the corporation in ultimate control is the natural starting-point. It was becoming that the fellows of Yale College, a collegiate school primarily for the education of the clergy, should be representative

[21] *Bull. Mus. Comp. Zool. Harvard Coll.*, Vol. 26, p. 278.